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F41F 1/02

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None

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UK CL (Edition J) F3C CFK
INT CL⁴ F41F

# (54) Electromagnetic launcher

(57) An electromagnetic launcher has a power supply 20 for supplying current pulses to five drive coils 21-25, each having its own pulsed current supply 27-31 and associated capacitor $C_1$–$C_5$ and magnetic switch $S_1$–$S_5$, the switches becoming conductive when the associated capacitor is substantially fully charged. As the projectile approaches, current is caused to flow in its coil 32 thus establishing a magnetic field which increasingly threads the drive coil 21. The current from supply 27 and that induced by the approach of the projectile are sufficient to open the switch $S_1$, a large pulse of current from the capacitor $C_1$ then being supplied to the drive coil 21 to accelerate the projectile. The remaining drive coils 22-25 and associated components operate in the same manner. In another embodiment (Fig 3), the power supply is in the form of a magnetic pulse compression line (42), and each drive coil (43, 44) of the launcher is coupled to a current loop of that line. In yet another embodiment (Fig 4), a transmission line (56) including saturable magnetic material forms the single drive member of the launcher.

Fig.2.

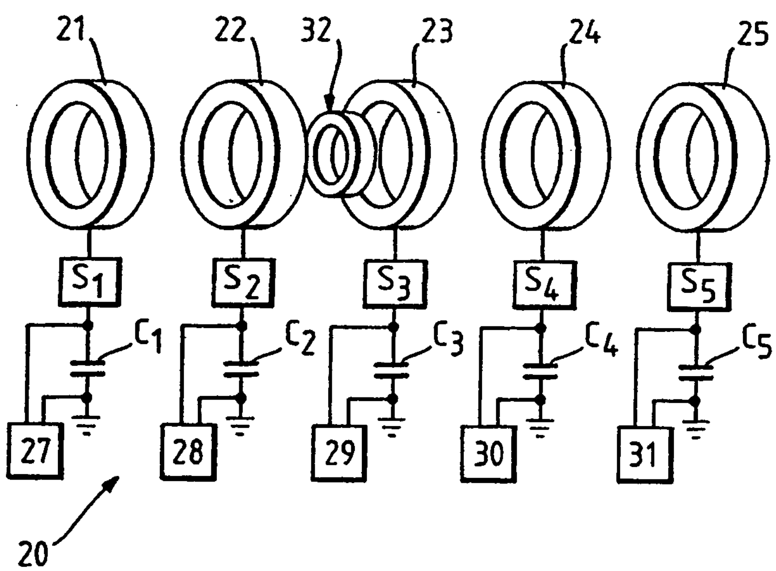


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Fig.1.

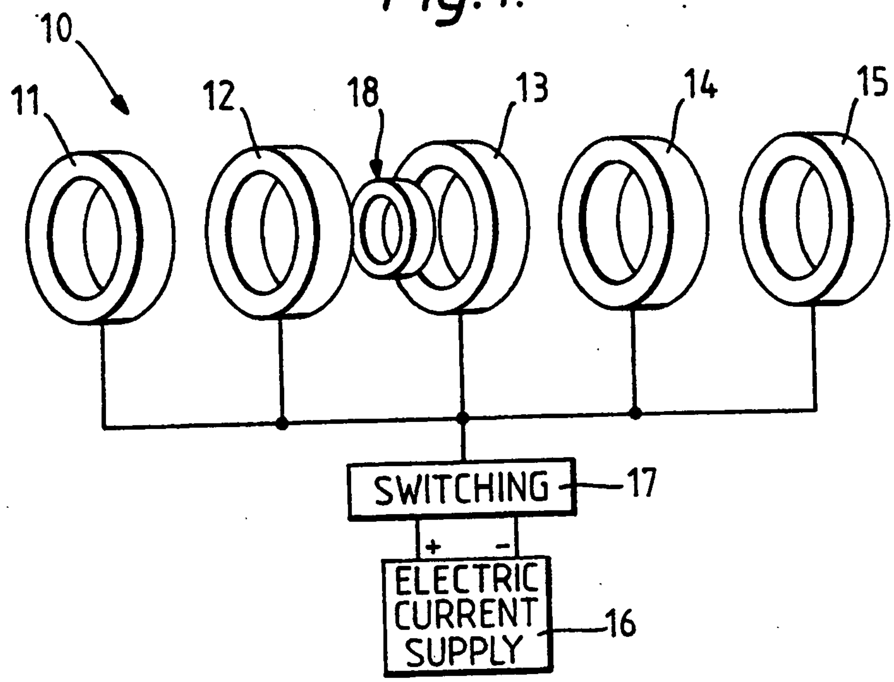

10
11
12
18
13
14
15
SWITCHING
17
+
-
ELECTRIC
CURRENT
SUPPLY
16

Fig.2.

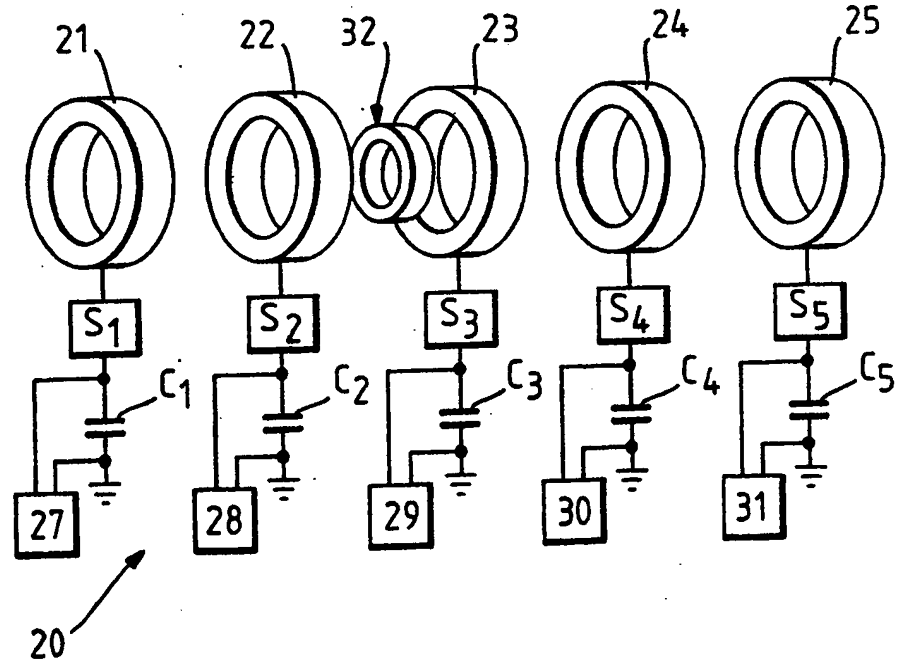

21
22
32
23
24
25
S1
S2
S3
S4
S5
C1
C2
C3
C4
C5
27
28
29
30
31
20

Fig. 3.

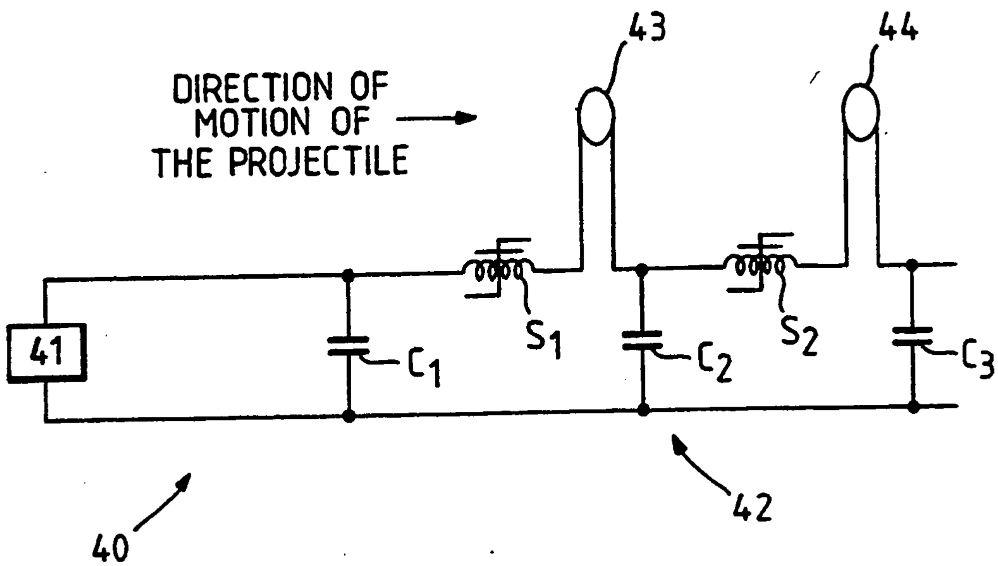
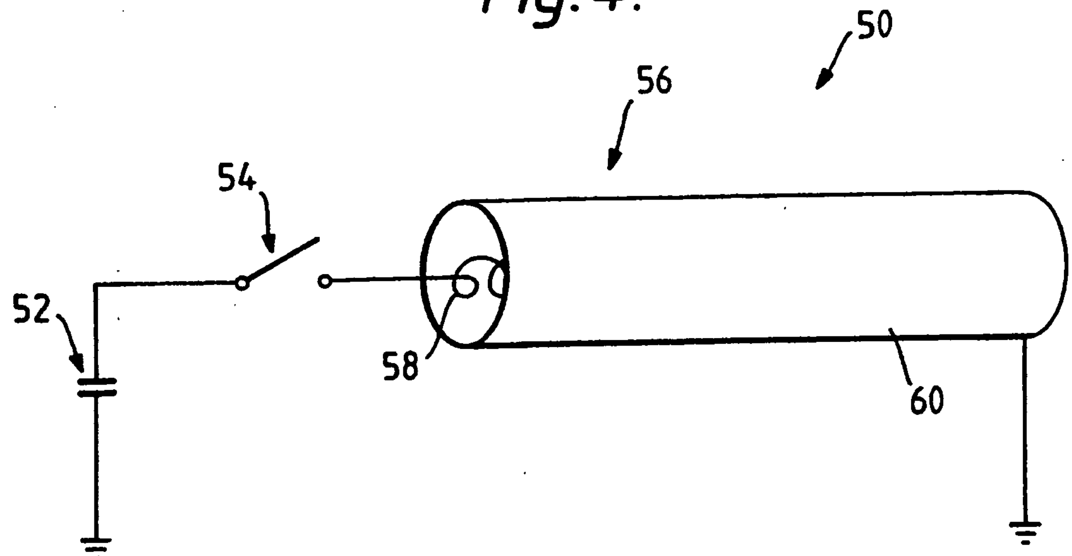

DIRECTION OF
MOTION OF
THE PROJECTILE
43
44
41
$C_1$
$S_1$
$C_2$
$S_2$
$C_3$
40
42

Fig. 4.


50
56
54
52
58
60

# ELECTROMAGNETIC LAUNCHER POWER SUPPLY

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The present invention relates to a power supply for an electromagnetic launcher.

Electromagnetic launchers utilise repulsive magnetic forces between current-carrying conductors. Figure 1 is a schematic representation of a known type of electromagnetic launcher - a co-axial electromagnetic launcher indicated generally at 10. The launcher 10 comprises five concentric drive coils 11 to 15, a current supply 16 and switch means 17 for supplying high current pulses to each of the drive coils.

The current supply 16 comprises a capacitor discharge circuit connected to each one of the drive coils 11 to 15, each discharge circuit being triggerable by a signal from a sensor positioned so as to detect the approach of a projectile to a particular drive coil.

The projectile comprises an electrical conductor, in this case a coil 18, configured to pass through the drive coils 11 to 15 and comprises a power supply for generating current in the coil 18 during launch.

In use, motion of the projectile may be initiated by a conventional gun or an auxiliary electromagnetic launcher. If the projectile travels from left to right in Figure 1, as it passes the drive coil 11 a high pulsed current is switched into the coil and this produces a pulsed axial magnetic field which interacts with the current flowing in the projectile coil 18 to produce an axial force to move the projectile rightwardly. As the projectile progresses through

the launcher 10, current pulses are switched into the coils 12 to 15 successively to produce subsequent pulsed axial magnetic fields so as to accelerate the projectile.

In practice, large forces are required to achieve high projectile velocities and this necessitates the use of high pulsed currents in both the drive coils and in the projectile coil and a close coupling between the drive and projectile coils to maximise exchange of energy. As the projectile accelerates, so the duration of strong coupling between the projectile coil and each drive coil shortens so that, ideally, the duration of the drive coil current pulses should become progressively shorter for the later coils.

There are difficulties associated with the known system described above. In particular, it is difficult to provide suitable switches to deliver high current pulses of the right shape and at precisely the right time to the drive coils 11 to 15 so as to coincide with the strongest interaction period of the projectile coil and each drive coil and to maximise efficiency.

It is also known to employ a helical transmission line in a drive member of an electromagnetic launcher. An electrical pulse is supplied to the line so as to generate a magnetic wave which travels along the line. The local velocity V of the electrical pulse is given by:-

$$V = \frac{1}{\sqrt{LC}}$$

where L and C are the local inductance and capacitance per unit length of the transmission line.

A degree of variation in the pulse velocity can be achieved by making L and/or C vary along the length of the line.

However, in practice it has been found that, as a projectile is accelerated along such a line, the leading edge of the pulse and the projectile may become unsynchronised thus lowering efficiency.

According to the present invention we provide a power supply for an electromagnetic launcher, the launcher having at least one electrically conductive drive member, comprising pulse generating means and circuit means including a saturable inductor for supplying current pulses to the drive member, and designed so that the approach of a projectile having an associated magnetic field to the or each drive member of the launcher induces a current in the circuit means.

Therefore, the impedance of the circuit means depends at least partly on the proximity of the projectile and the duration of the interaction between the projectile and the drive coil which depends on the velocity of the projectile. Advantageously, this property is utilised to make the power supply self-synchronising.

Magnetic switches in the form of saturable inductors are available for use in a power supply of the invention which are well suited to handling the high value current pulses required.

The power supply may be designed so that the approach of a current carrying projectile to the or each drive member of the electromagnetic launcher automatically triggers the supply of a

current pulse to the or each drive member. Thus the power supply can be made to be self-synchronising and self-switching which is very advantageous in that it obviates the need for dedicated switching and timing mechanisms to be provided.

In the embodiments to be described a power supply according to the invention is for an electromagnetic launcher having a plurality of drive members and comprises a saturable inductor associated with each drive member.

The power supply may comprise a magnetic pulse compressor having a plurality of current loops, each current loop comprising a saturable inductor.

Using a magnetic pulse compressor enables greater efficiency to be achieved because available energy which is not coupled to the projectile in any given pulse during a launch sequence can be utilised at a later stage in the sequence.

In an embodiment to be described each current loop is adapted to supply current pulses to an individual drive member.

Preferably, the power supply is adapted to supply current pulses of decreasing duration so as to take account of the acceleration of the projectile during launch.

According to a second aspect of the invention we provide an electromagnetic launcher comprising at least one drive member, the or each drive members being coupled to a power supply as hereinbefore described.

In another embodiment to be described the circuit means comprises a transmission line comprising saturable magnetic material.

The transmission line is configured to operate as a drive member of an electromagnetic launcher.

In that embodiment the power supply is designed so that a projectile having an associated magnetic field travels along the transmission line on the leading edge of an electromagnetic pulse propagating along the transmission line.

Addition of the saturable magnetic material causes an active interaction between the transmission line and a projectile which allows much better synchronisation of the travelling electrical pulse and the projectile than in known electromagnetic launchers comprising a transmission line.

Particular embodiments of the present invention are shown, by way of example in the accompanying drawings in which:-

In Figure 2 is a schematic representation of a first embodiment of a power supply according to the present invention;

Figure 3 is a schematic representation of a second embodiment of a power supply according to the present invention;

Figure 4 is a schematic representation of a third embodiment of a power supply according to the present invention.

In Figure 2 a power supply indicated generally at 20 is shown for supplying current pulses to five drive coils 21-25 of an electromagnetic launcher. Each of the coils 21-25 has its own pulsed current supply 27-31 and associated capacitor $C_1$-$C_5$ and magnetic switch $S_1$-$S_5$. Each of the magnetic switches $S_1$-$S_5$ comprises a saturable inductor which will switch from a non-conductive state to a conductive state in accordance with the magnitude of current to which

it is subjected in a well-known manner. The saturable inductor may be any square loop magnetic material such as a suitable ferrite or metallic glass.

The current supply circuits for the drive coils 21-25 are each designed so that the magnetic switch $S_1$-$S_5$ becomes conducting when the associated capacitor $C_1$-$C_5$ is fully charged or nearly fully charged.

The projectile coil is indicated at 32. As the projectile approaches, current is caused to flow in the projectile coil 32 thus establishing a magnetic field around the moving projectile. During approach of the projectile, the supply 27 delivers pulses of current to the capacitor $C_1$.

As the projectile approaches the first drive coil 21, the amount of the magnetic field around the projectile which threads the drive coil 21 increases. This increase in magnetic flux linkage induces a current in the drive coil 21 which also flows through the magnetic switch $S_1$ and this induced current is in the correct sense to drive the magnetic switch $S_1$ towards saturation.

The circuit is designed so that the current supplied from the supply 27 and that induced by the approach of the projectile is sufficient to cause the switch $S_1$ to saturate at a desired time. This time may be before the projectile coil 32 passes through the drive coil 21 in which case some of the projectile kinetic energy is converted to magnetic field energy associated with the projectile coil in a way which enhances the interaction between the projectile and the drive coil. Alternatively the switch $S_1$ may be arranged to saturate when the coils are co-planar. Alternatively the switch $S_1$ may be

arranged to saturate after the projectile coil 32 has passed through the drive coil 21 and the coils are in a position of strong interaction. This allows a large current pulse to be supplied to the drive coil 21 from the capacitor $C_1$ which accelerates the projectile as a result of electromagnetic repulsion.

The remaining drive coils 22-25 and associated components operate in just the same manner and are designed so that the switch $S_2$-$S_5$ associated with each drive coil 22-25 saturates to allow a large current pulse to be supplied to the drive coil 22-25 from the associated capacitor $C_2$-$C_5$ to accelerate the projectile.

Thus the arrangement of Figure 2 has valuable self-synchronising and self-switching properties thereby obviating the need for dedicated timing and switching devices for each drive coil.

In Figure 3 a power supply is indicated generally at 40 and comprises a pulsed current supply 41 connected to a magnetic pulse compression line 42. Only two stages (current loops) of the compression line 42 are shown in Figure 3.

A first drive coil 43 is connected into the first stage of the compression line 42 which comprises an input capacitor $C_1$ and a magnetic switch $S_1$ in the form of a saturable inductor. A second drive coil 44 is connected into the second stage of the compression line 42 which comprises an input capacitor $C_2$ and another magnetic switch $S_2$. The input capacitor $C_3$ for the third stage is also shown in Figure 3.

The power supply shown in Figure 3 is designed also to have the self-synchronising and self-switching properties described with reference to Figure 2.

The compression line 42 is designed so that the magnetic switch $S_1$ saturates owing to the combined effect of the charge on the capacitor $C_1$ and the current induced in the coil 43 by the approaching projectile. This allows a current pulse to flow to the capacitor $C_2$ through the drive coil 43 thereby accelerating the projectile. Likewise, the magnetic switch $S_2$ saturates due to the combined effect of the charge on the capacitor $C_2$ and the current induced in the drive coil 44 by the approaching projectile to allow a current pulse to flow to the capacitor $C_3$ through the drive coil 44 and so on for the remainder of the drive coils of the electromagnetic launcher.

Furthermore, the compression line 42 is arranged so that the duration of successive current pulses, applied to successive drive coils, progressively shortens. This helps to optimise energy transfer between the projectile coil and the drive coils as it takes account of the acceleration of the projectile during launch.

Moreover, any available energy generated at the first stage of the compression line 42 but which is not coupled into the drive coil 43 is transferred to the next stage for coupling into the drive coil 44 and so on. Thus efficiency is increased. As the approaching projectile interacts continuously with the drive coils and the pulse compression line, variations in the projectile approach velocity can be tolerated. Instead of the arrangements shown in Figures 2 and 3, one or more flux compressors, e.g. explosive flux compressors, may

be used to generate current pulses. Any other form of pulse generator suitable for providing the required current pulses may be used.

An electromagnetic launcher may take the form of a single stage boost having a single drive coil and the invention applies equally to such a case. Although electromagnetic launchers having drive members in the form of coils have been shown and described, the drive members may take the form of any electrical conductor suitable for achieving the required interaction with the electrical conductor on a projectile.

Another form of power supply 50 is shown in Figure 4 and comprises an energy storage capacitor 52, a switch 54 and a transmission line 56. The transmission line 56 has a helical inner conductor 58 and a cylindrical outer conductor 60 which is earthed. The transmission line 56 is generally of uniform cross-section. A current flowing along the inner conductor 58 produces an axial magnetic field within the helix and a circumferential magnetic field between the inner conductor 58 and the outer conductor 60. The volume between the inner and outer conductors is at least partly filled with saturable magnetic material.

The capacitance of the transmission line 56 may be formed by a continuous tube of dielectric material placed between the inner and outer conductors or may be formed from one or more discrete capacitors placed between the inner and outer conductors at intervals along the transmission line. The saturable inductor may also be in tubular form and may be inside or outside the dielectric tube if there is one. If discrete capacitors are used these will be connected to the inner

conductor 58 and to ground through an aperture in the saturable inductor.

Charge is supplied to the capacitor 52 by charging means (not shown). An electrical pulse propagates along the transmission line 56 when the charged capacitor 52 is connected to the line by closing the switch 54. The local velocity V of the electrical pulse is

$$V = \frac{1}{\sqrt{LC}}$$

where L and C are the local inductance and capacitance per unit length of the transmission line 56. The inductance per unit length of the line 56 is dependent on whether the magnetic material is saturated or unsaturated. When the magnetic material is unsaturated, the inductance L is high and the propagation velocity V is consequently low. When the magnetic material is saturated, the inductance L is low and the propagation velocity V is consequently high. When the switch 54 is closed initially, all of the line 56 is unsaturated and therefore the electrical pulse begins to propagate slowly along the line. If a projectile with an axial magnetic field is injected into the helical inner conductor 58 this induces a current in the helical conductor 58 which is in the correct sense to drive the magnetic material to saturation so as to allow the electrical pulse to propagate rapidly along the transmission line 56. Therefore as a projectile moves from left to right along the transmission line 56 the section of the line ahead of the projectile contains unsaturated magnetic material and supports a low electrical pulse propagation velocity. The section of

the line in the immediate vicinity of the projectile contains saturated magnetic material. This material is saturated by the magnetic field of the projectile and the propagating electrical pulse.

The system may be designed so that the projectile rides on the leading edge of the propagating electrical pulse. The rising edge of the electrical pulse has a magnetic field associated with it which interacts with the magnetic field of the projectile to drive the projectile forward. As the projectile is accelerated the projectile reaches higher velocities and moves along the transmission line, more quickly saturating the magnetic material as it goes. The electrical pulse will follow and its leading edge will keep up with the projectile as long as the projectile velocity does not exceed the maximum pulse propagation velocity which the saturated transmission line 56 can support.

The magnetic material may be saturated by the projectile magnetic field alone or by a combination of the projectile magnetic field and the magnetic field associated with the leading edge of the propagating electrical pulse. In either case the power supply 50 is designed so that the projectile sits on the leading edge of the electrical pulse and the projectile while the projectile is being accelerated.

Using a travelling wave to accelerate the projectile in this manner allows longer interaction time between an electrical pulse and a projectile than is the case with a simple drive coil. Thus the same energy can be imparted to the projectile over a longer time so allowing lower currents to be used.

In the embodiments which have been described the magnetic field around the projectile may be established by a permanent magnetic material eg. by making the projectile at least partly from a permanent magnetic material.

## CLAIMS

1. A power supply for an electromagnetic launcher, the launcher having at least one electrically conductive drive member, comprising pulse generating means and circuit means including a saturable inductor for supplying current pulses to the drive member, and designed so that the approach of a projectile having an associated magnetic field to the or each drive member of the launcher induces a current in the circuit means.

2. A power supply according to Claim 1 which is designed so that the approach of a projectile having an associated magnetic field to the or each drive member of the electromagnetic launcher triggers the supply of a current pulse to the or each drive member at a predetermined time.

3. A power supply according to Claim 1 or Claim 2 for an electromagnetic launcher having a plurality of drive members comprising a saturable inductor associated with each drive member.

4. A power supply according to any preceding claim comprising a magnetic pulse compressor having a plurality of current loops, each current loop comprising a saturable inductor.

5. A power supply according to Claim 4 in which each current loop is adapted to supply current pulses to an individual drive member.

6. A power supply according to Claim 4 or Claim 5 which is adapted to supply successive current pulses of decreasing duration.

7. An electromagnetic launcher comprising at least one drive member the or each drive member being coupled to a power supply as claimed in any preceding claim.

8. A power supply according to claim 1 wherein the circuit means comprises a transmission line comprising saturable magnetic material.

9. A power supply according to claim 8 wherein the transmission line is configured to operate as a drive member of an electromagnetic launcher

10. A power supply according to claim 9 designed so that a projectile having an associated magnetic field travels along the transmission line on the leading edge of an electromagnetic pulse propagating along the transmission line.

11. A power supply according to any one of claims 8 to 10 comprising an outer electrical conductor surrounding an inner electrical conductor and saturable magnetic material placed therebetween.

12. A power supply according to claim 11 wherein the inner conductor is helical.

13. A power supply according to claim 11 or 12 comprising dielectric material placed between inner and outer conductors.

14. A power supply according to claim 11 or claim 12 comprising one ore more capacitors placed between the inner and outer conductors.

15. A power supply substantially as herein described with reference to, and as illustrated in, Figure 2, Figure 3 or Figure 4 of the accompanying drawings.

16. An electromagnetic launcher substantially as herein described with reference to, and as illustrated in, Figure 2, Figure 3 or Figure 4 of the accompanying drawings.

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